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16. ABSTRACT

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The relationships may be useful in forecasting changes in the size and structure of benthic communities in response to changes in solids emissions and in providing guidance for the design and execution of responsive monitoring surveys.

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FORECASTING EFFECTS OF SEWAGE SOLIDS ON MARINE BENTHIC COMMUNITIES

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JOURNAL ARTICLE

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Abstract. Solids from marine municipal discharges settle to the sea bottom where they cause major but potentially reversible changes in the biomass and trophic structure of macrobenthic communities. Analysis of data from macrobenthic surveys around five southern California coastal discharge sites indicates that there are significant exponential relationships between the mass emission rate of solids and the size of altered macrobenthic communities. Size was expressed both in terms of biomass (metric tons, mt, wet wt) and area (km^2) occupied by communities dominated by surface and subsurface deposit-feeding organisms.

The relationships may be useful in forecasting changes in the size and structure of benthic communities in response to changes in solids emissions and in providing guidance for the design and execution of responsive monitoring surveys.

INTRODUCTION

Municipal wastewaters contain a mixture of gross and trace constituents that, in the absence of toxic concentrations of pollutants, can increase the abundance of a number of benthic invertebrate species and decrease the abundance of others (Smith, 1974; Word *et al.*, 1977; Young and Young, this volume). At present, it is possible to forecast which benthic species will increase or decrease in response to a particular kind of discharge or input (Word *et al.*, 1977; Pearson and Rosenberg, 1978; Rhoads *et al.*, 1978). It also has been demonstrated that recovery to normal benthic community structure can take place when discharge is terminated (Smith, 1974; Pearson and Rosenberg, 1978).

While helpful, this kind of information is not sufficient for dischargers and regulatory agencies to assess the total ecological costs and benefits of alternative treatment strategies. How much marine life is affected? Will a proposed change in emissions change the total environmental impact by 50%, 75%, or 90%? Needed are predictive relationships between the amount of sewage discharged and the magnitude of biological changes resulting from the discharge. Relationships should be expressed in terms that are easy to understand and that have an impact on decision makers. We believe such relationships exist, and we demonstrate here several such relationships derived from assessments of conditions at a suite of southern California deepwater municipal sewage discharges.

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BACKGROUND

The five discharges and discharge areas cited in this report (Figure 1) are especially suited for examining quantitative relationships between pollutant inputs and biological responses. Each of the five has one or more outfalls that have been discharging relatively constant amounts of sewage for one or more decades (Schafer, 1977, 1979). Each discharges subtidally at similar depths (20-60 m) and into similar hydrographic and faunal regimes. All discharge sites also are subjected to predominantly longshore currents that are variable but have similar energy spectra (Hendricks, 1977). Although the contaminant inputs of individual discharges may differ from one another by as much as two orders of magnitude, depending on the contaminant, each discharge emits relatively constant amounts of bioactive materials, especially suspended solids, which contain much of the biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, and phosphorus (Schafer, 1977, 1979).

In all effluents most of the trace and gross constituents (metals, chlorinated hydrocarbons) are associated with or attached to particulates. These particulates, or suspended solids, are discharged at rates ranging from 1,000 to over 100,000 metric tons per year (mt/yr). Both field and laboratory measurements indicate that between 10% and 20% of the particulates settle to the sea floor at most sites (Herring and Abati, 1979). The particulates create elliptical zones of contamination centered around the outfalls, which cover from several to nearly 200 square kilometers (Young *et al.*, 1976; Eganhouse *et al.*, 1978; Young *et al.*, 1978; Bascom, 1979).

During the past decade there have been frequent benthic invertebrate surveys around each discharge site and at distant control areas (Smith, 1974; Mearns and Greene, 1976; Smith and Greene, 1976; Word *et al.*, 1977; Bascom, 1979; Word, 1979b; Mearns, 1981). Increased biomass, decreased species diversity, and a shift from suspension- to deposit-feeding benthic communities are among the responses common to these wastewater discharges (Mearns and Greene, 1976; Word *et al.*, 1977). Word (1979b) described this shift in terms of an Infaunal Trophic Index (ITI), which is described below. The changes are similar to those observed in areas where increased inputs of organic carbon and nitrogen into surface sediments have led to the increases in the production of more tolerant deposit-feeding species at the expense of more sensitive detrital-feeding species (Smith *et al.*, 1973; Pearson and Rosenberg, 1978; Young and Young, this volume).

Initial comparisons of benthic communities at the California sites revealed that the increase in average biomass (expressed as g/m^2), decrease in average diversity (H'), and area of the sea floor (expressed in km^2) over which significant changes occurred were approximately proportional to sewage flow and mass emission rate of suspended solids but were poorly correlated with concentrations of suspended solids or other contaminants (Mearns and Greene, 1976; Mearns and Young, 1978; Bascom *et al.*, 1979). On the basis of these observations, mathematical formulations were developed linking solids mass emission rates

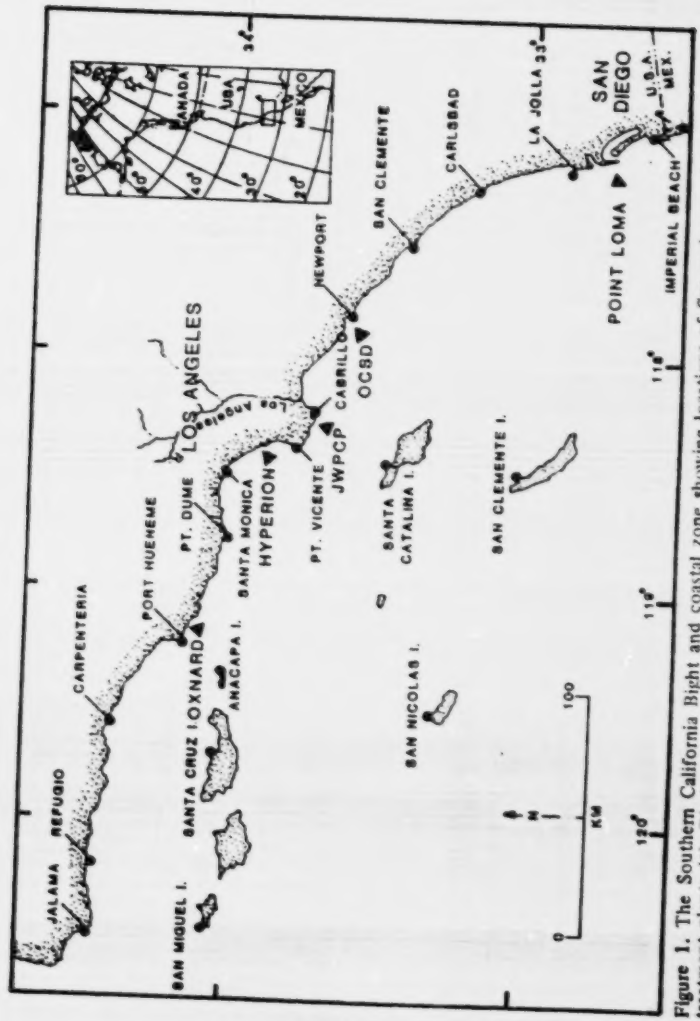

Figure 1. The Southern California Bight and coastal zone showing locations of five major municipal wastewater treatment plants (▲). Dischargers, discharge depths, and flows: Oxnard–20 m, 42.4 x 10^6 liters/day, and 11-km (7-mi) sludge outfall–90 m, 17.4 x 10^6 liters/day; Joint Water Pollution Control Plant (JWPCP). County of Los Angeles–60 m, 1,268 x 10^6 liters/day; Orange County Sanitation Districts (OCSD)–60 m, 681 x 10^6 liters/day; Point Loma Treatment Plant, City of San Diego–60 m, 439 x 10^6 liters/day.

(independent variable) and the size of the impacted area or mass of organisms affected (dependent variable). This was done because it was felt that more attention would be drawn to a response involving tens or hundreds of square kilometers and impacting hundreds or thousands of tons of organisms, than to responses involving the traditionally-expressed biomass (g/m^2) or information theory species diversity (H or H') averaged over a set of stations. Thus, in the following analysis, commonly used sample variables such as biomass are presented in terms that reflect the magnitude of benthic community changes (*i.e.*, metric tons of excess standing crop, area occupied by excess standing crop, or area occupied by abnormal abundances of deposit-feeding organisms). The relationships also are used to forecast benthic conditions that may result from alterations in sewage inputs or waste treatment.

METHODS

Inputs

Each of the five major southern California dischargers measures flow and gross effluent constituents from daily and weekly composites. Schafer (1977, 1979) computed annual mass emission rates from these measurements. For suspended solids, these values in 1977 were: 1,500 mt from Oxnard, 20,500 mt for Point Loma, 33,300 mt from Orange County, a combined total of 78,800 mt from Hyperion Treatment Plant sludge and effluent, and 102,000 mt from the Joint Water Pollution Control Plant (JWPCP).

For this report, data on suspended solids mass emission rates for 1977 were compared to ITI's computed using 1977 and 1978 benthic survey data. In addition, averaged 1975-1977 suspended solids mass emission rates were compared to average benthic standing crops from 1975-1977 surveys. This procedure was required because the total suite of data for computing both biomass and other indices of community structure during 1975-1977 was not taken in the same surveys.

Benthic Surveys

Since 1973 each discharge site was sampled by at least four and by as many as 14 synoptic benthic macrofaunal grab surveys, with two to four replicate samples taken at from 10 to 44 stations, depending on the survey site (Mearns and Greene, 1976). Various devices (from 0.04-m^2 Shipek grabs to 0.16-m^2 Van Veen grabs) and several screen sizes were used in the surveys. An overall summary of the samples inspected for this report is presented in Table 1.

Differences resulting from heterogeneous collection methods were studied (Word, 1976; Word *et al.*, 1976a), and abundance and biomass data were adjusted to comparable units (densities or biomass per square meter). More recent sample collections were made with uniform procedures (0.1-m^2 Van Veen, 1.0-mm screen). Techniques for identification, enumeration, and weighing also were standardized among all present monitoring and investigative groups

Table 1. Summary of monitoring and research benthic surveys that provided data used in this study. Agency abbreviations: AHF–Allan Hancock Foundation, University of Southern California; JWPCP–Joint Water Pollution Control Plant, County of Los Angeles; LA–City of Los Angeles; OCSD–Orange County Sanitation District; PLTP–Point Loma Treatment Plant, City of San Diego; SCCWRP–Southern California Coastal Water Research Project. Frequencies: A–annual; Q–quarterly; S–semiannual.

Site of survey	Agency	Survey period	Approximate grid size (km^2)	Number of stations	Number of replicates	Frequency	Screen size (mm)	Sampling device	Reference
Monitoring surveys									
Oxnard	City	1974	27	19	3	Q	0.5	Shipek	M.B.C., Inc., 1975
		1976-1978	1	7	3	Q	0.5	Shipek	Unpublished data
Santa Monica Bay	LA	1971-1977	197	22	4	S	1.0	Shipek	Unpublished data
		1978-1979	197	22	1	S	1.0	Van Veen	Unpublished data
Palos Verdes	JWPCP	1973-1979	62	40	4	S	1.0	Shipek	Unpublished data
		1979	62	18	4	S	1.0	Van Veen	Unpublished data
Orange County	OCSD	1974-1976	20	18	3	Q	1.0	Forest-Petersen	Unpublished data
		1976-1979	20	17	2	A	1.0	Van Veen	Unpublished data
Point Loma	PLTP	1973-1975	30	18	3	S	1.0	Petersen	Unpublished data
		1976-1979	30	17	4	Q	1.0	Van Veen	Unpublished data
Research surveys									
60-m control	SCCWRP	Apr.-Aug. 1977	–	70	1	Once	1.0	Van Veen	Word and Mearns, 1979
Synoptic shelf	SCCWRP	Feb.-Dec. 1978	1,800	310	1	Once	1.0	Van Veen	Bascom, 1979
Orange County	SCCWRP	Mar. and Aug. 1975	35	35	≥2	Twice	1.0 and 5.0	Van Veen	Greene, 1976
Grab comparison	SCCWRP	Dec. 1974 and Mar. 1975	–	4	60-80	Once	1.0, 0.7, and 0.5	8 types	Word, 1976
Entire coastal shelf	AHF	1956-1958	3,900	176	1	Once	0.7	Orange peel	Allen Hancock Foundation, 1965

(Word *et al.*, 1976b; Word, 1977). This provided an internally consistent taxonomic data base.

Charts showing contoured data from areal surveys are presented by Bascom (1979) for Santa Monica Bay, Palos Verdes, Orange County, and Point Loma; by M.B.C., Inc. (1975) for Oxnard; and by Greene (1976) for Orange County.

Estimating the Magnitude or Size of Affected Populations

Three variables were chosen from the surveys to estimate the overall size of affected benthic communities. First, the overall excess standing crop (mt) of infauna around each of the five major discharge sites shown in Figure 1 was estimated. Values of benthic biomass (g/m^2) for discrete single surveys were plotted and contoured to reveal the size and shape of regions of enhanced biomass (*i.e.*, above control values). The total area of each contour was measured by planimetry, and the products of average biomass (g/m^2) and area (m^2) were summed. The difference between the sum for each outfall area and that for expected total biomass, based on average values for adjacent control transects, was taken as an estimate of the excess standing crop (mt, wet wt) for each site and survey.

Contours of benthic biomass also were used to estimate the total area (km^2) occupied by the excess standing crop. This was used as a second, but not necessarily independent, measure of the size (km^2) of the affected community.

The third variable chosen was the area (km^2) occupied by infaunal communities dominated by deposit-feeding organisms, as determined by the ITI. The ITI is a numerical description of the distribution of four groups of selected macrofaunal invertebrate species in a grab sample. The ITI is calculated as follows:

$$ITI = 100 - \left[33.\bar{3}\left(\frac{0N_1 + 1N_2 + 2N_3 + 3N_4}{N_1 + N_2 + N_3 + N_4}\right)\right],$$

where N_i = the number of individuals in group "i". The groups contain species that largely are distinguished by feeding categories, as shown in Table 2, and described in more detail by Word (1979a,b). Values of the ITI range between 0 (dominated by subsurface deposit-feeding invertebrates) and 100 (dominated by suspension-feeding invertebrates). Recent studies (Bascom *et al.*, 1979; Word, 1979b) confirm that the ITI is inversely correlated with the concentration of organic matter in surface sediments (which, in waste discharge areas, is related to the mass emission rate of wastewater organic matter and suspended solids). Species presently used in the ITI (Table 2) account for at least 60% of the individuals collected in southern California macrobenthos samples taken on the open coastal shelf in fine sediments at depths between 20 m and 200 m. Additional attributes and the logic behind development and application of the ITI are described elsewhere (Word, 1979a,b).

Table 2. Groups of species considered in calculating the Infaunal Trophic Index. The wastewater discharge factor affecting the abundance of each group appears to be the deposition or accumulation of organic particulate material (Word, 1979a, b). UI = unidentified form.

Group and description	Species	
I. Suspension feeders primarily; dominant in control or background areas; decrease in abundance with increasing proximity to wastewater discharges; 19 species, 7 taxa.	*Amphiodia (Amphispina) urtica* *Amphiodia (Amphispina) digitata* *Amphiodia psara* *Amphiodia occidentalis* *Amphiodia* spp. *Ampelisca pacifica* *Ampelisca hancocki* *Ampelisca brevisimulata* *Ampelisca macrocephala* *Ampelisca cristata*	*Paraphoxus bicuspidatus* *Metaphoxus frequens* *Heterophoxus oculatus* *Ampelisca* sp. *Paraphoxus* sp. *Metaphoxus* sp. *Heterophoxus* sp. *Sthenelenella uniformis* *Phoronis* sp.
II. Surface detritus feeders; may be abundant in control areas but are not dominant; increase in abundance in areas slightly affected by wastewater discharges; 14 species, 7 taxa.	*Photis brevipes* *Photis californica* *Photis* spp. *Euphilomedes producta* *Euphilomedes carcharodonta* *Euphilomedes longiseta*	*Mediomastus* spp. *Myriochele gracilis* *Myriochele* sp. *Axinopsida serricata* *Mysella pedroana* *Mysella tumida*
III. Surface deposit feeders primarily; often present but never abundant in areas moderately affected by wastewater discharges; 4 species, 4 taxa.	*Parvilucina tenuisculpta* *Macoma carlottensis* *Bittium* spp. *Spiochaetopterus costarum*	
IV. Subsurface deposit feeders; rare at control sites; most abundant in areas heavily affected by wastewater discharges; 10 species, 8 taxa.	*Armandia bioculata* *Schistomeringos longicornis* *Schistomeringos* sp. *Ophryotrocha* sp. Dorvilleidae, UI[1]	*Capitella capitata* Tubificidae, UI *Solemya panamensis* *Solemya* sp. Stenotholdae, UI

[1] Undescribed species, D. Montagne, Los Angeles County Sanitation Districts, Whittier, California (personal communication).

ITI values were calculated from over 300 Van Veen grab samples taken around the five major urban outfall discharge sites (Bascom, 1979) and at distant control sites (Word, 1979b; Word and Mearns, 1979). Distant areas unaffected by municipal waste discharges had ITI values that ranged from 83 to 100 (*i.e.*, dominated by suspension-feeding invertebrates). ITI values between 60 and 80 occurred near outfall and non-outfall sites and indicated a fauna still numerically dominated by detrital-feeding invertebrates. Values below 60 (*i.e.*, fauna dominated by deposit-feeding invertebrate species) occurred almost exclusively near outfall sites. Areas with ITI values between 30 and 60 (dominated by surface deposit-feeding infauna) were considered "changed", and areas with ITI values below 30 (dominated by subsurface deposit-feeding infauna) were

considered "degraded" (Bascom *et al.*, 1979). The sizes of affected areas within each site were measured by planimetry.

Correlation with Inputs

Once computed, estimates of the size of affected areas and excess standing crops were plotted against suspended solids mass emission rates. Correlations and bestfit lines were computed using linear regression techniques on log transformed data.

RESULTS

During 1977 there was a 100-fold range of nutrient, BOD, and suspended solids mass emission rates among the five major discharges (*i.e.*, suspended solids ranging from 1,500 mt/yr at Oxnard to 102,000 mt/yr at Palos Verdes) (Table 3). Previous data (Schafer, 1977) indicate these emissions have been relatively constant during the past decade.

Contours of sediment volatile solids, an indicator of sediment organic content (Mitchell and Schafer, 1975), benthic infaunal biomass, and ITI indicate that the size and shape of affected bottom areas vary among the discharge sites. For example, at Point Loma, volatile solids increased from a background of 2.8% to a high value of 5.6% near the outfall, while benthic biomass increased from 70 g/m^2 to 120 g/m^2, and the ITI dropped from 93.5 to 33. Overall, a total of 5.5 km^2 exhibited elevated biomass, and 4 km^2 were characterized by ITI values below 60 (Table 4). In contrast, peak values for volatile solids and benthic

Table 3. Total mass emission rates and concentrations of various constituents in southern California discharges, 1977 (Schafer, 1979). ND = no data.

	JWPCP	Hyperion[1]		Orange County	Point Loma	Oxnard
		8 km	11 km			
Flow						
Total (liters/day x 10^6)	1,268	1,207	17.4	681	439	42.4
Total suspended solids						
Total (mt/yr)	102,000	27,300	51,500	33,300	20,500	1,500
Concentration (mg/liter)	220	62	8,100	132	128	98
Five-day BOD						
Total (mt/yr)	102,000	63,900	ND	47,900	26,700	3,900
Concentration (mg/liter)	220	145	ND	197	167	258
Ammonia nitrogen						
Total (mt/yr)	18,000	7,590	1,650	9,830	3,810	317
Concentration (mg/liter)	39	17.2	259	36	23.8	20.5

[1] Two outfalls, one 8 km (5 mi) with a combined effluent of primary and secondary wastes and the second 11 km (7 mi) with waste-activated sludge, discharge within 3 km of each other in Santa Monica Bay.

biomass at Palos Verdes reached 27% and 879 g/m^2, respectively, and the ITI reached a minimum of 0.3. Overall, an area >94 km^2 was characterized by ITI's below 60 (Table 4). Conditions in Santa Monica Bay and off Orange County were intermediate (Mearns and Greene, 1976; Bascom *et al.*, 1979). At Oxnard, the smallest discharge site, there were no stations with ITI's below 60, and an area of less than 0.01 km^2 was affected (Table 4).

It is apparent in Table 4 that both excess standing crops and areal extent of enhanced biomass and depressed ITI values generally vary with suspended solids mass emission rates. As a first approximation, the relationships between suspended solids mass emission rates (J_e) and benthic effects are exponential and can be described by linear regressions of $\log_{10}$ transformed data (Figures 2,3,4).

FORECASTING

The strong correlations between solids mass emission rates and the magnitude of benthic response (Figures 2, 3, 4) are assumed to be indicative of a cause-effect relationship. Thus, it should be possible to forecast changes in the size and

Table 4. Summary of estimates of excess standing crops (mt, wet wt) and areas (km^2) occupied by excess standing crop and Infaunal Trophic Indices (ITI's) characteristic of deposit-feeding communities at five southern California waste discharge sites. MER = mass emission rate. Values computed from results of macrobenthic surveys taken between 1975 and 1977 for excess standing crop and its area, and in 1978 (Bascom, 1979) for ITI's ≤ 60 and ≤ 30.

	Oxnard	Point Loma	Orange County	Santa Monica Bay	Palos Verdes
Suspended solids MER (mt/yr) 1975	2,181	18,725	33,396	110,180	130,966
1977	1,500	20,500	33,300	78,800	102,000
Excess standing crop (mt) 1975-1977	17	150	455	5,625	11,760
Area (km^2) occupied by excess standing crop	1	5	5	30	45
Area (km^2) occupied by benthic assemblages with ITI					
≤ 60	0 (< 0.01)[1]	≤ 4.0	10.8	> 57.7	> 94
≤ 30	0 (< 0.01)[1]	≤ 0.16[2]	0.25[3]	3.3	8.4

[1] Not detected; arbitrary assignment.

[2] One station within 0.4 km of outfall had value < 30 on several occasions. Limit of detection based on station density in grid.

[3] One station within 0.5 km of diffuser had value < 30 on one occasion. Limit of detection based on station density in grid.

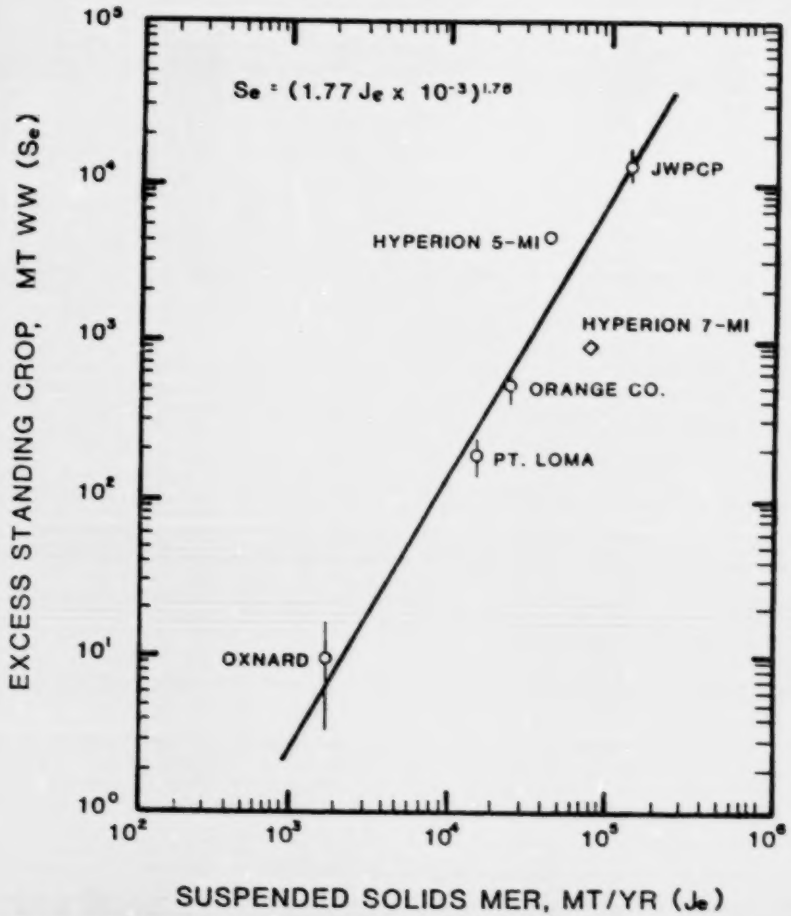

Figure 2. Relation between suspended solids mass emission rates (J_e, mt/yr) and total excess standing crop of benthic infauna (S_e, mt wet wt) surrounding six outfalls on the southern California mainland shelf. Hyperion 8-km (5-mi) effluent and 11-km (7-mi) sludge outfalls plotted separately. Circles and diamond indicate average excess standing crop; bars indicate range of standing crops for each location.

general composition of these benthic macrofaunal communities that would accompany increases or decreases in the mass emission rates of solids. Some aspects of making such forecasts are considered below.

Characteristics of the Relationships

Inspection of exponents in the equations of Figures 2, 3, and 4 indicates that each community variable has a different response to increases or decreases in

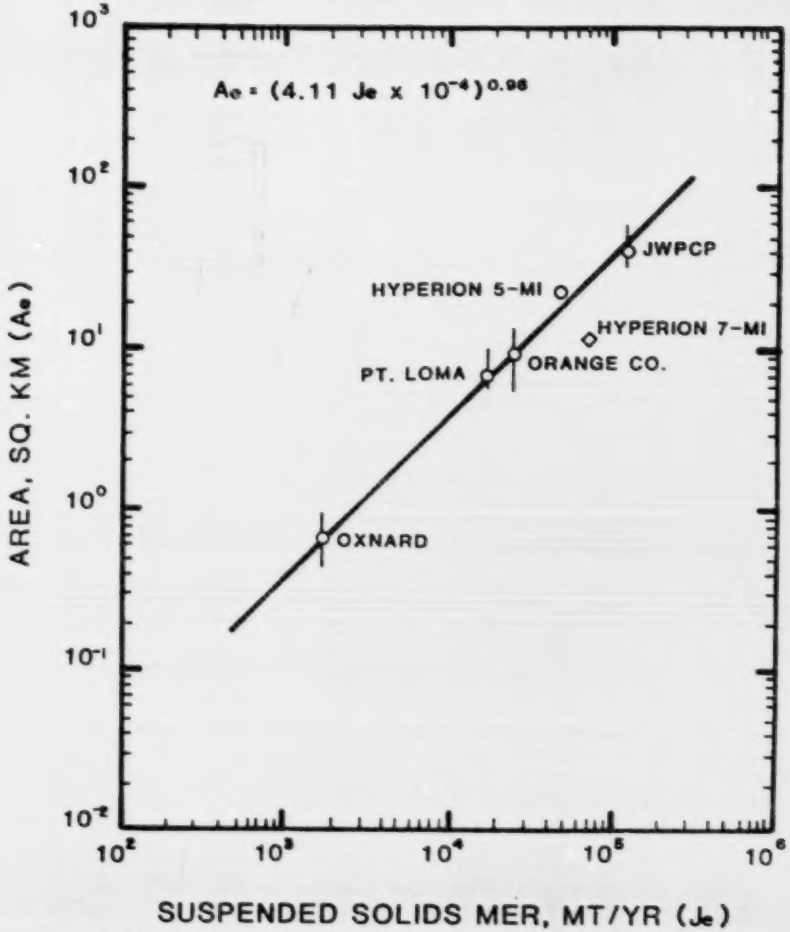

Figure 3. Relation between suspended solids mass emission rates (J_e, mt/yr) and size of areas (km^2) occupied by total excess standing crop (A_e) of infauna surrounding six outfalls on the southern California mainland shelf. Circles and diamond indicate average of area occupied by excess standing crops; bars indicate ranges for each location.

suspended solids emission. For example, back calculations (Table 5) indicate that doubling suspended solids emissions from 25,000 mt/yr to 50,000 mt/yr (typical range of values for moderate outfalls) will increase (1) the excess standing crop by a factor of 3.4 (from 759 mt to 2,553 mt), (2) the area occupied by that standing crop by a factor of 2 (from 9.4 km^2 to 18.2 km^2), (3) the area occupied by both surface and subsurface deposit-feeding infauna (characterized by ITI's ≤ 60) by a factor of 4.5 (from 5 km^2 to 22 km^2), and (4) the area

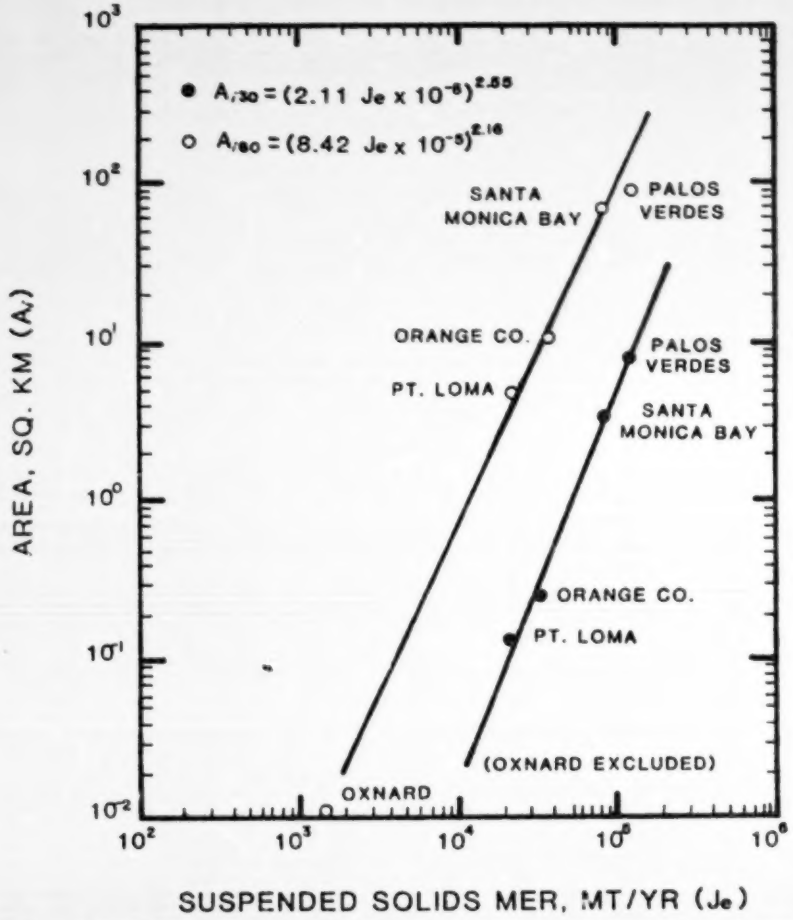

Figure 4. Relation between suspended solids mass emission rates (J_e, mt/yr) and size of areas (A_i, km^2) occupied by macrobenthic fauna dominated by subsurface deposit-feeding organisms ($i < 30$) and by surface and subsurface deposit-feeding organisms ($i < 60$); calculations based on the Infaunal Trophic Index (ITI, see text). Data points represent values from surveys reported by Bascom (1979). There were no samples with ITI's < 30 at Oxnard.

occupied only by subsurface deposit feeders (such as *Capitella capitata*) by a factor of 5.9 (from 0.02 km^2 to 1.14 km^2).

Forecast for a Southern California Ocean Outfall

In 1978 an intergovernmental agency asked the Coastal Water Research Project to forecast ecological benefits of proposed reductions of specific wastewater constituents in several southern California effluents. The largest

Table 5. Calculations of macrobenthic excess standing crops (S_e), areas occupied by excess standing crops (A_e), and areas occupied by macrobenthic communities dominated by both surface and subsurface deposit-feeding organisms (A_{i60}) or only by subsurface deposit-feeding organisms (A_{i30}) for a wide range of annual suspended solids mass emission rates (MER).

Suspended solids MER (mt/yr)	Macrobenthos response S_e (mt)	A_e (km^2)	A_{i60} (km^2)	A_{i30} (km^2)
10,000	153	3.9	0.7	0.018
25,000	759	9.4	5.0	0.0195
50,000	2,553	18.2	22.4	1.141
70,000	4,600	25.1	46.0	2.69
100,000	8,588	35.4	100.4	6.68
165,560[1]	20,753	57	299	24.2

[1] New York Bight sewage sludge (Mueller *et al.*, 1976).

reduction was to occur in the discharge off Palos Verdes where the 1975 suspended solids emission of 131,000 mt/yr was to be reduced by 85% to 19,900 mt/yr. In fact, this discharger will soon implement secondary treatment of 756×10^6 liters/day (200 mgd) of a total flow of about $1,323 \times 10^6$ liters/day (350 mgd). Actual effluent quality forecasts are not yet available, but in the interim an 85% removal of suspended solids for the 756×10^6 liters/day (200 mgd) flow is assumed. This would produce a combined flow of 43,000 mt/yr of suspended solids. In addition, solids emission from this discharge already has decreased to about 104,000 mt/yr in 1979.

Using the equations described in Figures 2, 3, and 4, predictions were made of infaunal benthic conditions that might prevail with the reduced emissions. As shown in Table 6, the 1979 emissions are forecast to produce slight (12% to 22%) decreases in the areas dominated by subsurface deposit-feeding infauna (*i.e.*, degraded, A_{i30}), the area occupied by excess standing crop (A_e), and the weight of the excess standing crop (S_e). However, no measurable change in area dominated by combined surface and subsurface deposit-feeding infauna (A_{i60}) is forecast. This lack of change results, in part, from a survey grid that did not completely encompass the affected area (*i.e.*, > 97 km^2).

In contrast, implementation of the facilities now under construction (*i.e.*, 756×10^6 liters/day secondary treatment) could result in reduced effects on the benthos, ranging from a 64% decrease in area occupied by excess standing crop (A_e) to a 91% decrease in area dominated by subsurface deposit-feeding infauna (to 0.8 km^2). The net effect would be a total bottom area of 16 km^2 that would harbor about 1,990 mt of excess infauna of abnormal composition. Within this impacted area, less than 1 km^2 would be dominated by subsurface deposit-feeding infauna (Group IV and some Group III species, Table 2). Full treatment, as proposed by the intergovernmental task force, would reduce further the total affected area to about 7.5 km^2, within which would occur about 510 mt of

Table 6. Forecast of changes in infaunal benthos parameters off Palos Verdes in 1979, when partial secondary treatment is implemented and if full secondary treatment is implemented. Percent reduction from 1975 conditions are given. See Table 5 for abbreviations.

	1975	1979[1]	Future	
			Partial treatment[2]	Full treatment[3]
Solids, MER, mt/yr	131,000	104,000 (21%)	43,300 (67%)	19,900 (85%)
S_e (mt)	11,760	9,200 (22%)	1,985 (83%)	510 (96%)
A_e (km^2)	46	37 (18%)	16 (64%)	7.5 (83%)
A_{i60} (km^2)	< 94	109 (112%)[4]	16 (83%)	3.1 (97%)
A_{i30} (km^2)	8	7 (12%)	1 (91%)	0.1 (99%)

[1] Actual measured input with forecasts of infaunal benthos parameters

[2] Assuming a combination of 567 x 10^6 liters/day (150 mgd) of existing primary effluent with 33,300 mt/yr suspended solids plus 756 x 10^6 liters/day (200 mgd) of secondary effluent with 85% removal of suspended solids (10,000 mt/yr discharged).

[3] Under conditions assigned by intergovernmental task force (Mearns, 1978).

[4] No detectable change; 1975 survey underestimated area affected

excess infaunal biomass, a 3.1-km^2 area of changed infaunal community structure, and a very small, possibly undetectable, 0.11-km^2 area dominated by subsurface deposit-feeding organisms (Table 6).

It would be tempting to conduct an incremental analysis of energy and treatment cost vs. magnitude of ecological change suggested by these forecasts; however, not all of the data required for such an analysis are in hand at this time. Nevertheless, these forecasts may have an intermediate benefit to the discharger and to regulatory agencies in that they represent hypotheses that could be tested by revised monitoring programs.

Application to the New York Bight

It is not certain whether the relationships described above will be applicable to the New York Bight or other coastal areas where sewage solids are discharged or dumped. Based on a mass emission (dumping) rate of 165,560 mt/yr for barged sewage solids into the apex (computed from Mueller *et al.*, 1976), there may be an excess standing crop of infauna of approximately 21,000 mt occupying an area of 57 km^2. In addition, an area of about 300 km^2 may be dominated by surface and subsurface deposit-feeding infauna, within which 24 km^2 may be dominated by subsurface deposit-feeding infauna (Table 5). To our knowledge, biomass has not been determined from apex benthic surveys, but Boesch (this volume) refers to an area on the order of 10-15 km^2 that supports a depauperate fauna and is surrounded by a larger area of 240 km^2, characterized as an "enhanced transitional area." In addition, our inspection of data in Steimle *et al.* (this volume) suggests that an area of 150 km^2 is nearly devoid of ampeliscid amphipods. These organisms are suspension feeders, and in southern California are among the first to disappear from areas impacted by sewage outfalls. These organisms occur in samples characterized by ITI > 60 but are rare where ITI ≤ 60. These estimates of measurable change in benthic communities are well within a factor of two projections, presented in Table 5, suggesting that the techniques described in this paper might be applicable to the New York Bight and should be explored further.

Uncertainties and Limitations

Applying the described approach to southern California and other locations, such as the New York Bight, requires a careful reexamination of each assumption and the inclusion of other information, such as corrections for differences in the settling rates of suspended solids (Herring and Abati, 1979). There also are a number of uncertainties and problems with the present approach; consequently, we recommend that relationships and equations be tailored to individual situations. The assumption that mass emission rates are relatively constant has been valid for several discharges but not for others (*e.g.*, those at Palos Verdes where discharges have been decreasing). More importantly, none of the benthic surveys were designed for estimating total population size, and only a few (Bascom, 1979) were designed for clearly resolving the size and shape of affected bottom areas. New surveys should be conducted to estimate more accurately both parameters, and new equations should be computed. This study also included an outfall (Oxnard) that was significantly shallower than the rest (20 m vs. 60 m). Even if the solids settling characteristics of this effluent were identical to those from the other outfalls, the increased current and wave action inshore could lead to alterations in the size of the affected area and to an underestimate of the impact of the Oxnard suspended solids mass emission (1,500 mt/yr) on benthic communities, were it discharged in deeper water.

This analysis also assumes that the relation between benthic biomass and suspended solids results from the nutritive (organic carbon) content of the solids, that all effluent solids have the same assimilative capacity, and that production and cropping (mortality) rates are proportional to emissions at all sites. We know, in fact, that solids from waste-activated sludge discharged via the Hyperion 11-km (7-mile) outfall have a different organic (BOD) content than the solids remaining in the 8-km (5-mile) effluent. As an extreme example, it would be inappropriate to compare effects of suspended solids of dredged material with those from the same discharge of sewage solids. In addition, we know from stomach content analysis that the infauna is indeed cropped by fishes, but at unknown rates. Finally, we also assume that toxic effects are of second order importance. We think this is true for most of the California study sites except Palos Verdes, where high concentrations of H_2S and DDT have prevailed over a large area (Smith and Greene, 1976) within which low biomass occurs.

Despite these problems and uncertainties, further development of untraditional approaches, such as this, is needed to resolve real management problems

and to provide a more quantitative approach for projecting the full magnitude of effects of discharges on benthic communities.

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